Investigating the underlying mechanisms of the Enactment Effect: The role of action-object bindings in aiding immediate memory performance.

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Abstract

Previous research has established that enacted action-object phrases lead to superior immediate memory performance compared to purely verbal memory. In the current investigation, Experiment 1 examined how enactment separately affects immediate memory for actions and objects in 24 adults by presenting action-object phrases and asking participants to recall either the actions or the objects presented in correct serial order. The results showed that when employed at presentation, enactment led to superior recall performance compared to verbal repetition, but this effect was significant only for memory for actions and not objects. Enactment during immediate recall did not lead to better memory performance compared to verbal recall for either actions or objects. In order to examine whether the lack of an enactment at recall was due to the splitting of action-object phrases at retrieval, Experiment 2 (n=24) examined memory for whole action-object phrases under enactment at recall. The results showed a typical enactment at recall benefit. Furthermore, a novel binding analysis suggested that enactment recall increased the likelihood of action features being remembered in a bound pair rather than alone. Together these findings suggest that action-object bindings play a crucial role in the manifestation of the enactment effect in immediate recall, especially when enactment is employed at the recall phase.

Introduction

When asked to memorise a set of instructions such as “lift the ball” or “tap the table” participants’ performance is typically better when they physically carry out these action phrases as opposed to verbally repeating them during the encoding stage (Engelkamp & Zimmer, 1995; Steffens et al., 2009). This phenomenon is known as the enactment effect or Subject Performed Task (SPT) effect and it was first studied as a phenomenon in the long-term memory literature (Cohen, 1981; Engelkamp et al., 1994). However, studies have also shown a memory advantage of enactment over verbal repetition during the encoding phase of immediate recall tasks (Allen et al., 2019; Allen & Waterman, 2015) as well as at both immediate and long-term retrieval (Badinlou et al., 2018) This has led to a growing body of research that has examined the potential benefits of enactment in a short-term memory context (e.g., Gathercole et al., 2008; Jaroslawska et al., 2016; Jaroslawska et al., 2018, Waterman et al., 2017). Such studies typically present participants with a set of sentences that each include a verb and an object (e.g. throw the ball) which then have to be recalled in correct serial order immediately after list presentation. Understanding the processes that support memory for a series of instructed actions that have to be performed immediately or soon after their presentation has clear applied implications for task learning and educational settings.

The benefits of enactment encoding on immediate recall are thought to rely on additional motoric and visuospatial information present during physical performance that in turn facilitate memory recall (Allen & Waterman, 2015; Waterman et al., 2017). Allen and Waterman (2015) were the first to examine enactment at encoding effects in immediate recall. Their findings showed that verbal recall of instructions was greater after enactment encoding compared to verbal encoding. Furthermore, Allen et al. (2019) examined the effects of demonstration (where participants observe someone else performing the actions) compared to verbal encoding in immediate memory recall. In this study, during the encoding phase participants watched a video of the experimenter performing each set of instructions (demonstration presentation) or listened to each set of instructions (auditory presentation). Between the presentation of each set of instructions there was a 3 second delay during which participants either performed the instructions (in the enactment encoding condition) or passively waited for the next set of instructions to play (in the no-enactment condition). This created 4 encoding conditions; demonstration with enactment, demonstration with no-enactment, auditory presentation with enactment and auditory presentation with no-enactment; recall was always verbal. The results showed that enactment at encoding improved immediate verbal recall performance when coupled with verbal instructions but did not provide any added benefits when combined with demonstration. Indeed, demonstration led to superior memory performance compared to verbal presentation independently of whether it was accompanied by enactment. These findings suggest that although enactment encoding benefits are well established in long-term memory research, these are somewhat less obvious in immediate recall.

In addition to examining the potential benefits of enactment at encoding, studies of enactment in immediate recall have also explored the effects of asking participants to enact their recall, finding consistent evidence of a benefit of enacted recall compared to verbal responding (see Jaroslawska et al., 2018; Yang et al., 2014; Yang et al., 2016). This is in contrast to LTM studies (see Brooks & Gardiner, 1994; Kormi-Nouri et al., 1994; Saltz & Dixon., 1982) that have not observed consistent enactment at recall benefits (though see Kubik et al., 2020; Norris & West, 1993). In studies that examine enactment at the response phase in immediate recall, participants are asked to recall the instructions by enacting them, which typically results in better memory performance. For example, in addition to manipulating the mode of encoding, Allen and Waterman (2015) also compared enacted as opposed to verbal recall. They showed an overall benefit of enacted recall, with participants recalling a significantly greater number of items when recall was through enactment independently of encoding mode (enactment or verbal). However, there was no "dual benefit" to performance when enactment was manipulated at both encoding and recall (similar results have since been observed with children see Jaroslawska et al., 2016; Waterman et al., 2017). These findings demonstrate that enactment at both encoding and recall does not lead to double enactment benefits in immediate recall. The enactment at recall effects also showed that processing during encoding was dependent on subsequent recall mode. In other words, it appears that participants encoded the information in a different manner when they knew they would be asked to recall it through enactment. This fits with the assumption that awareness of the need for enactment at recall triggers additional spatial-motor processing during the encoding of information, in other words that enactment recruits additional spatial-motor planning that facilitates performance (Koriat, Ben-Zur & Nussbaum, 1990).

A theoretical framework that could potentially explain the effects of enactment – whether at encoding or at recall – in tasks that require immediate serial recall is that of working memory (WM), a limited capacity cognitive system that temporarily holds and manipulates information (Baddeley, 2010). However, accumulating evidence suggests that, compared to verbal learning, physically enacting instructions leads to superior immediate memory performance even when participants engage in concurrent distractor tasks aimed to disrupt WM processing (Yang et al., 2016). For instance, Yang et al. (2014) used phonological, visuospatial and central executive distractor tasks during phonological encoding while manipulating the opportunity for enactment at recall. They found that although immediate recall performance was impaired by all distractors under both recall conditions (i.e. verbal recall, enactment recall), the enactment recall advantage remained intact (Yang et al., 2014; Yang et al., 2016). These findings led Yang et al. (2014) to suggest that the enactment advantage does not depend on WM resources and that cognitive systems beyond WM are involved in enactment performance even in immediate recall. Others have instead advocated the existence of an additional “motor store” system that operates within WM and is responsible for the enactment advantage observed in immediate recall tasks (Jaroslawska et al., 2016; Jaroslawska et al., 2018; see also Yang et al., 2019).

Although the precise underlying cause of any benefits of enactment is not fully established, it is generally believed that performing physical actions, or planning to do so, generates some form of action-motor plans (Engelkamp & Zimmer, 1984; Jaroslawska et al., 2016; Koriat et al., 1990; Zimmer & Engelkamp, 1985). If the recruitment of motor action plans is indeed the underlying cause of the enactment effect, then it is reasonable to assume that enactment might benefit more, or indeed only, memory for verbs as opposed to other sentence elements (such as nouns) since it is the action itself that is enacted.

Partial evidence for the assumption that the enactment advantage relies on superior memory for actions per se in the context of immediate recall was provided in the study by Yang et al. (2014) that used WM distractors at encoding while manipulating enactment at recall. They reported that the enactment advantage over verbal recall was specific to action words rather than other sentence elements (i.e. objects and objects' features). However, in addition to investigating memory for action-object pairs after verbal or demonstration presentation coupled with self-enactment or auditory/visual encoding (see above), Allen et al. (2019) examined the effects of encoding for actions and objects (Experiment 1), finding that only demonstration at encoding and not enactment enhanced memory for actions.

In related work, Yang et al. (2016) employed a similar paradigm to Yang et al. (2014) but additionally investigated binding of instruction features (actions, objects, and object's colour) under enactment and verbal recall. More specifically, they examined how often the correct object and object feature (i.e. colour) was retrieved after the correct action was recalled under enactment and verbal recall. They found that compared to verbal recall, enactment at recall enhanced memory for action-object bindings. These findings suggest that the relationship between action and object within action-object pairs may also play a role in successful enactment memory performance in immediate recall.

Overall, the findings from the aforementioned studies suggest that enactment benefits in immediate recall might be driven by action words, with action-object bindings also contributing to the enactment effect (for relevant findings in LTM research see Engelkamp et al., 1990). However, these assumptions are based on a post-hoc review of the evidence and the effects of enactment on immediate recall of different sentence elements are yet to be examined directly. Therefore, the present study aimed to explore this idea further by examining separately action and object memory for integrated verb-noun pairs under enactment or verbal encoding and enactment or verbal retrieval in immediate recall. Following the approach of Allen and Waterman (2015), the present experiment tested all four possible combinations of enactment vs. verbal encoding and enactment vs. verbal retrieval modes. Crucially, this study also included the novel manipulation of probe type so that at the end of each trial participants had to recall *either* just the actions *or* just the objects presented during encoding. This allowed as to test directly the effects of enactment for each component of the pair (i.e. actions, objects). In other words, the separation of action-object phrases at recall, enabled us to investigate whether enactment benefits equally memory for actions and memory for objects. This enactment versus verbal memory task for actions versus objects was named the Instructed Action Feature Task (IAFT).

The central aim was to investigate whether enactment effects are driven by actions per se (rather than other elements such as objects) under all enactment encoding and retrieval conditions within an immediate serial recall paradigm. It was expected that if the underlying mechanism that gives rise to the enactment effect relies on purely motoric processing, then a benefit for the actions but not objects would be observed. If, however, enactment leads to better memory for actions as well as objects, then that would suggest that the benefits of enactment go beyond purely motoric processing. Finally, if action-object bindings play an important role in the manifestation of the enactment effect, then there is a possibility that splitting the action-object information at recall would reduce any enactment advantage.

Therefore, Experiment 1 examined enactment benefits for actions and objects with the aim of identifying if memory for actions and objects within action-object pairings is affected equally by physical enactment. Based on previous findings, it was expected that a memory advantage after enactment encoding as well as after enactment retrieval would be observed, but predominantly for actions.

Experiment 1

Method

Participants

24 young adults ($Mean_{age}$ = 22.4 years, SD_{months} = 4.48) took part in a one-hour long session at the University of Bristol. Participants gave their full consent in writing and verbally. They were paid £7 for their participation. Ethical approval for this study was secured from the appropriate institutional review board – the University of Bristol Faculty of Science Human Research Ethics Committee.

Material

The stimuli used in the Instructed Action Feature Task (IAFT) were 9 foam objects (approximately 5cm x 4cm each) in the shape of numbers 0 to 8 and eight verbs. These objects were chosen after careful consideration; numbers are familiar shapes but at the same time abstract enough to avoid any obvious semantic associations or familiar pairings between verbs and objects. The 9 foam objects were divided into two sets; objects 1 to 8 formed one set and object 0 the other. The zero shaped object was used separately as a neutral object to perform the actions on in the enactment recall conditions. All foam objects (0 to 8) were of the same colour blue. The 8 verbs indicated the actions to be performed on the other 8 foam objects. The action verbs used in this study were chosen from a larger pool of verbs on the basis of their distinctiveness after pilot work. Those verbs were *"push, shake, tap, drop, turn, rub, squeeze, lift*". The 8 verbs and the 8 numbers created a total of 64 action-object pairs. A trial consisted of either 5 or 6 action-object pairs and those were presented in a randomised order. This trial length was shown to be the most optimal after pilot work. The pairs were pseudorandomised to ensure that no action or object appeared twice in the same trial or in the exact same position in the previous or next trial. In total 4 blocks were created, each with a unique combination of object-action pairs per trial. A group of 16 trials created a block. Each action-object pair appeared once in each block of trials and a total of 3 or 4 times across all blocks. The presentation order of these blocks remained fixed across all participants while the order of the encoding-recall conditions was counterbalanced across these blocks. The order of the four encoding-retrieval conditions were counterbalanced across participants. The task was created and presented in Microsoft PowerPoint.

Design

The instructed action task employed a 2x2x2x2 repeated measures design manipulating encoding mode (verbal vs. enactment), retrieval mode (verbal vs. enactment), probe type (action vs object) and trial length (five or six sentences per trial). The dependent variable for the instructed action task was serial recall accuracy.

Procedure

Participants faced towards a table on which the foam shape numbers were present at all times. Participants completed a set of five practice trials before the presentation of each block. Each trial consisted of five or six action-object pairs (arranged pseudo-randomly). Each pair included an action verb and a number object (i.e., squeeze the 5, drop the 1, push the 4, tap the 7, shake the 3). Pairs were auditorily presented at a rate of 1 per 1200 milliseconds. The recorded voice was modified so that auditory presentation length for each verb and each number lasted precisely 600 milliseconds each. There was a 4 seconds delay between the presentation of each action-object pair during which participants either verbally repeated the instruction or enacted it, depending on the encoding mode (for an example of a trial see Figure 1). After each trial participants saw an image on the screen that indicated retrieval of either the objects or the actions presented in that trial (ordered pseudo-randomly). For the objects, the image signalling recall displayed lots of numbers in a random fashion. For the actions, the image cueing action recall displayed a raised hand with the palm open. Depending on the retrieval mode (enactment or verbal) participants retrieved the items either through enactment or verbally. Participants were instructed to retrieve the items in the correct order. The foam shapes were randomly re-arranged after every 4 or 5 trials. The experimenter sat on the left-hand side of the table and recorded participants' responses manually using a laptop.

Procedure for the four conditions of the IAFT

During encoding, participants listened to the pre-recorded instructions. During the 4 seconds delay between the presentation of each pair, participants either enacted the pair (enactment encoding), or verbally repeated it (verbal encoding). At the end of the trial participants saw an image that indicated the probe type to be recalled (actions or objects). In enactment recall, participants either pointed at the objects if it was an object trial, or performed the actions on the 0 shaped object, if it was an action trial. In verbal recall, participants either verbally recalled the objects if it was an object trial, or verbally recalled the actions if it was an action trial.

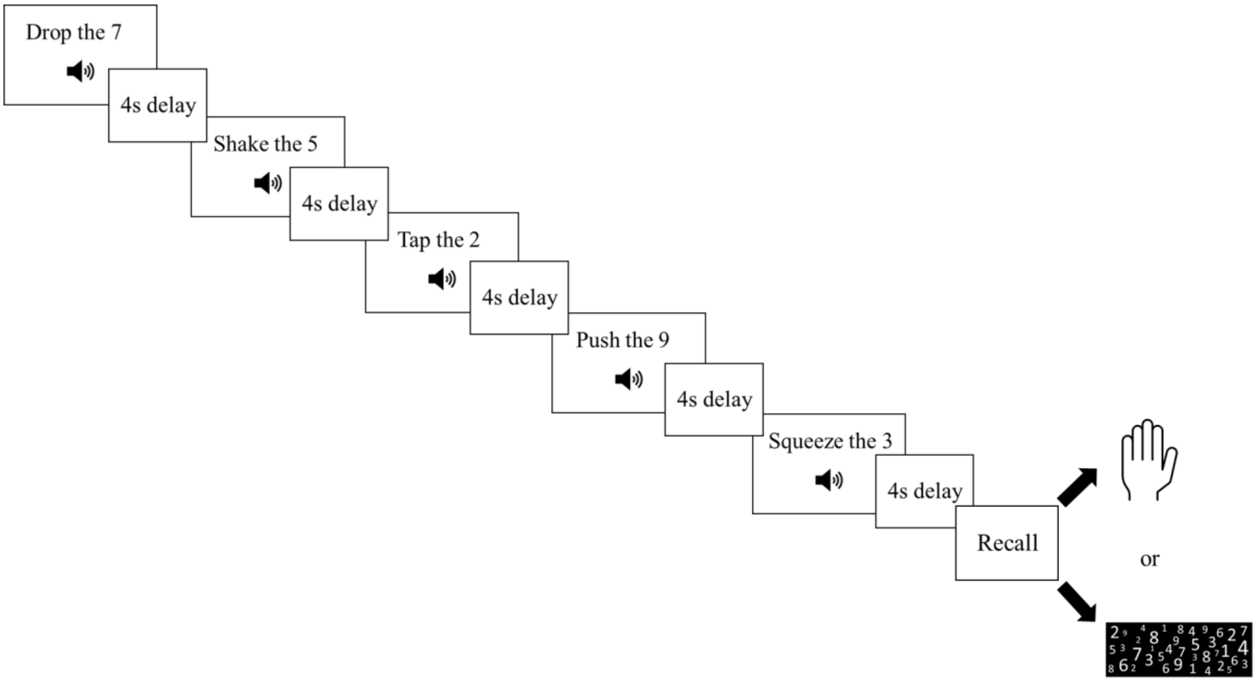


Figure 1. Example of a trial (length 5) during encoding. Each instruction pair was presented auditorily and there was a 4-seconds delay between each pair during which participants either performed the instructions using the foam objects (in the enactment encoding blocks) or verbally repeated the instructions (in the verbal encoding blocks). At the end of the trial participants saw an image similar to the pictures displayed in this example, signifying the probe to be recalled (either a picture of a hand for the actions or a picture of numbers for the objects).

Results

Scoring

Responses were scored as correct when the correct item was retrieved in the correct position in the list. The proportion correct for each condition was calculated by averaging responses across trials. The resultant descriptive statistics can be seen in Table 1.

Table 1

Means and standard deviations reflecting proportion correct performance in each of the encoding and retrieval conditions for trial length 5 and 6 under serial recall scoring.

			Actions	Objects
Encoding	Recall	Trial Length	*Mean (SD)*	*Mean (SD)*
E	E	5	.51 (.27)	.60 (.24)
E	E	6	.30 (.24)	.41 (.22)
E	V	5	.45 (.28)	.72 (.18)
E	V	6	.30 (.18)	.51 (.20)
V	E	5	.33 (.14)	.72 (.23)
V	E	6	.22 (.15)	.54 (.24)
V	V	5	.35 (.25)	.62 (.28)
V	V	6	.22 (.20)	.55 (.28)

Initially, the data were analysed using a preliminary 2x2x2x2 (probe type x encoding mode x recall mode x trial length) repeated measures analysis of variance which revealed a significant interaction between probe type and encoding mode, $F(1, 23) = 7.866$, $p = .010$, $\eta_p^2 = .255$, a significant interaction between probe type, encoding mode and recall mode, $F(1, 23) = 8.113$, $p = .009$, $\eta_p^2 = .261$, and a significant interaction between encoding mode and trial length, $F(1, 23) = 5.122$, $p = .033$, $\eta_p^2 = .182$. There was also a 4-way interaction between probe type, encoding mode, recall mode and trial length that was close to significant, $F(1, 23) = 4.134$, $p = .054$, $\eta_p^2 = .152$.

Given these interactions, the data were then split according to probe type to separately investigate the different effects of encoding and recall modes and trial length on actions and objects. A 2x2x2 (encoding mode x recall mode x trial length) analysis of variance revealed a significant main effect of trial length for the action recall data, $F(1, 23) = 48.376$, $p < .001$, $\eta_p^2 = .678$ and for the object data, $F(1, 23) = 45.887$, $p < .001$, $\eta_p^2 = .666$, but trial length did not interact significantly with any other factor. Given that there were no significant interactions with trial length for the objects or the actions, it was decided to collapse across trial lengths for the following core analysis.

This 2x2x2 (probe type x encoding mode x recall mode) analysis of variance, collapsed across both trial lengths showed a significant main effect of probe type, $F(1, 23) = 64.420$, $p < .001$, $\eta_p^2 = .737$, but no reliable effect of encoding mode, $F(1, 23) = 0.936$, $p = .343$, $\eta_p^2 = .039$, or recall mode.

$F(1, 23) = 0.518$, $p = .479$, $\eta_p^2 = .022$. Further, it replicated the patterns shown in the four-way analysis: the interaction between probe type and encoding mode was significant, $F(1, 23) = 7.752$, $p = .011$, $\eta_p^2 = .252$, but was qualified by a significant interaction between probe type, encoding mode and recall mode, $F(1, 23) = 7.140$, $p = .014$, $\eta_p^2 = .237$. In order to investigate this 3-way interaction further, a final pair of 2x2 (encoding mode x retrieval mode) repeated measures ANOVAs were performed separately for each probe type (actions, objects). The results of these analyses are shown in Table 2.

Table 2

Effects of encoding and retrieval mode for actions and objects

	Actions			Objects		
	F	p	η^2	F	p	η^2
Encoding mode	7.88	.01	.26	1.68	.21	.07
Recall mode	0.12	.72	.01	1.26	.27	.05
Encoding x Recall	0.84	.36	.04	12.48	< .01	.35

As Table 2 shows, the interaction between encoding mode and recall mode was not significant for actions, but was significant for objects (compare Figures 2 and 3). Post-hoc comparisons examining the encoding mode by recall mode interaction for objects showed that enactment encoding with verbal recall led to better object recall compared to enactment at both encoding and recall $F(1, 23) = 11.794$, $p = .002$, $\eta_p^2 = .339$. On the contrary, the difference between verbal encoding with enactment recall and verbal encoding with verbal recall did not reach significance, $F(1, 23) = 0.796$, $p = .382$, $\eta_p^2 = .033$. Enactment recall of objects was significantly superior after verbal encoding compared to enactment encoding $F(1, 23) = 12.113$, $p = .002$, $\eta_p^2 = .345$. However, verbal recall of objects was not significantly different after enactment or verbal encoding $F(1, 23) = 0.113$, $p = .740$, $\eta_p^2 = .005$.

In summary, the key finding of Experiment 1 was a significant three-way interaction between probe type, encoding mode and recall mode. Memory for actions benefited from enactment encoding but not enactment recall (see Figure 2). In contrast, memory for objects, though generally higher than that seen for actions, was poorer when enactment was present at both encoding and recall compared to the other three conditions (see Figure 3).

Figure 2

Performance for the actions in the four conditions. Error bars represent the standard error of the mean.

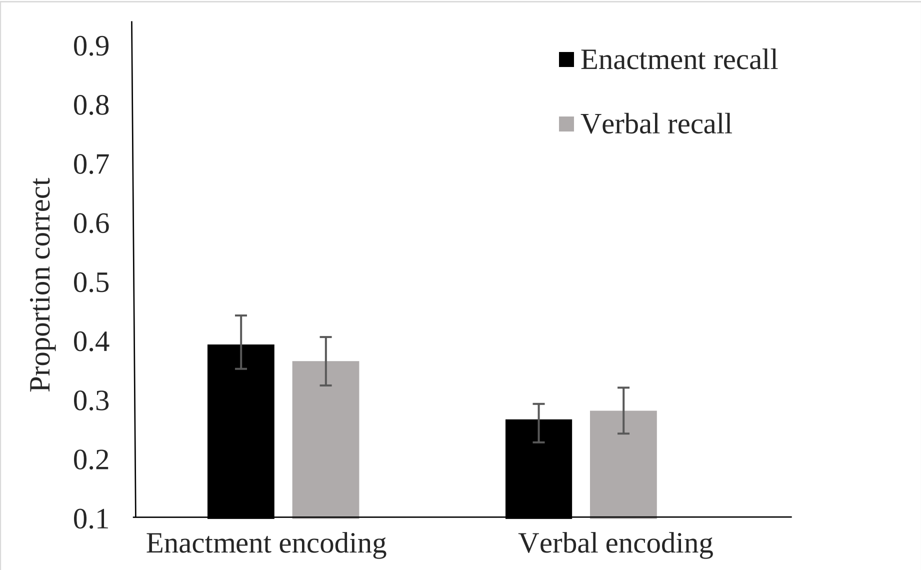
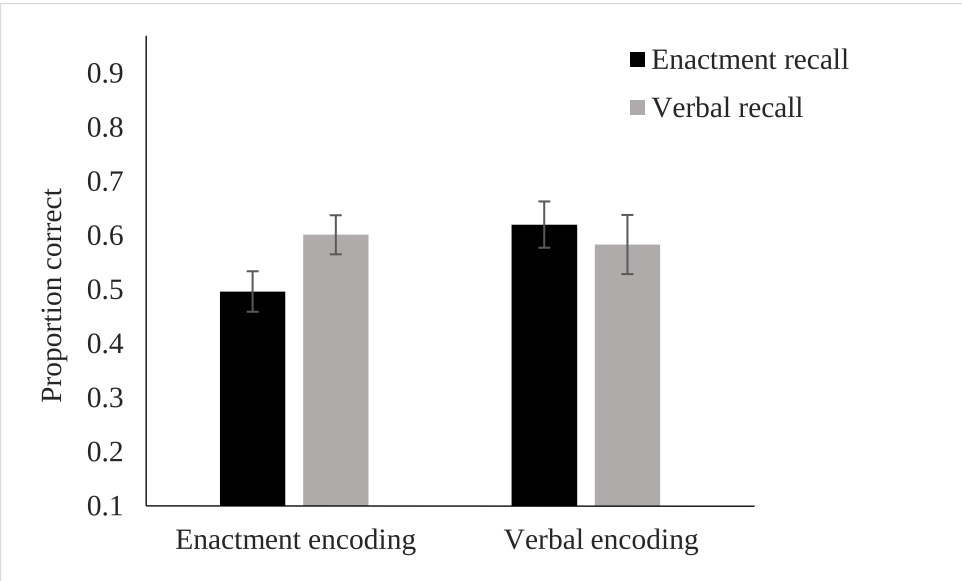


Figure 3

Performance for the objects in the four conditions. Error bars represent the standard error of the mean.



Finally, previous research by Engelkamp (1997) on enactment in LTM indicated that the benefits of enactment at recall are diminished when enactment encoding is manipulated within-subjects, but not when it is examined between-subjects (though see Jahn & Engelkamp, 2003). To ensure that the current findings were not due to the within-subjects nature of the study design, we examined whether the order of encoding condition completion (enactment or verbal encoding condition first) had any effect on performance. This analysis compared the level of performance in the verbal encoding with enactment recall condition among participants who completed the two verbal encoding conditions first to that seen in participants who completed the two enactment encoding conditions first. If enactment encoding negatively affects enactment recall performance, it would be expected that enactment recall performance would be higher for the participants who completed verbal encoding conditions first compared to those who completed enactment encoding first. An independent samples t-test showed no significant difference in performance as a function of encoding condition completion for either the actions $t(22) = -1.093$, $p = .286$, or the objects $t(22) = -0.348$, $p = .731$. Thus, the results of the current investigation are not consistent with the view that participants' experience of enactment encoding in a within-subjects design carries over to detrimentally affect their subsequent enactment recall performance.

Discussion

The aim of Experiment 1 was to examine whether enactment benefits in an immediate serial recall task involving the presentation of a sequence of action-object pairings are mainly driven by a memory superiority for actions per se (as opposed to objects). The main prediction was that memory for actions would benefit from enactment encoding and enactment retrieval. The results indicate that memory for actions was indeed significantly better after enactment compared to verbal encoding, independently of retrieval mode. However, enactment at recall did not lead to superior performance for the actions compared to verbal recall. Overall, memory for the objects did not benefit from enactment at encoding or at recall. However, an encoding by recall mode interaction for the objects was observed. This showed that verbal encoding with enactment recall and enactment encoding with verbal recall led to better performance compared to enactment at both stages, but not compared to the verbal encoding and verbal recall condition. Thus, although enactment seemed to facilitate object memory when it was employed at one stage (encoding or recall) compared to enactment at both stages, performance in these conditions was still not superior to the verbal encoding and verbal recall condition. Thus, within the current paradigm, enactment did not facilitate memory for objects.

The fact that enactment at recall did not facilitate memory for actions or objects is in agreement with previous studies in the LTM literature (see Brooks & Gardiner, 1994; Kormi-Nouri et al., 1994 Saltz & Dixon., 1982) which observed enactment at encoding but not enactment at recall benefits for action-object pairs (but see also Kubik et al., 2020). However, some LTM studies have observed enactment at recall benefits when instructions involved body parts (e.g. shake your head) rather than external (present or absent) objects (see Kormi-Nouri et al., 1994; Norris & West, 1993).

The absence of any enactment at recall benefits in our immediate recall task was contrary to initial predictions and is not consistent with previous literature that has observed enactment recall benefits in WM (e.g. Allen & Waterman, 2015; Yang et al., 2016; Jaroslawska et al., 2018). Enactment at the recall phase is thought to enhance performance by the recruitment of action-motor plans laid down during encoding for later execution (Koriat et al., 1990). Perhaps, selectively retrieving one component of the action-object pairing during retrieval in the current study prevented participants from forming these plans at encoding. This could be because participants had to encode the action-object phrases as one unit, but during retrieval participants had to perform the actions on a different object (zero) or point at the numbers. This change in the 'object of performance' may have indeed disrupted the formation of motor action plans. If so, then it may be suggested that enactment does not rely on purely motoric processing but also on other elements such as the object of performance and by extension, action-object bindings. Thus, the findings from this study indirectly suggest that action-object bindings play an important role in the enactment effect, at least at enactment recall.

Additionally, the absence of enactment recall effects suggest that enactment encoding and enactment recall involve different processes. This is because memory for enacted actions during encoding was not hindered by the splitting of the action-object phrases at retrieval but enactment at recall failed to enhance performance. These results are consistent with Kormi-Nouri et al. (1994) who found that, compared to well-integrated action-object pairs, poorly integrated pairs experienced a reduced benefit of enactment at recall in a LTM context while enactment encoding benefits for these pairs remained intact. Their findings provide further evidence that action-object bindings affect enactment memory performance, especially when enactment is manipulated at recall. However, in order to directly test these assumptions a further experiment examined enactment only at recall using the same basic instructions as Experiment 1 but with participants recalling the whole action-object phrase.

Experiment 2

This study aimed to investigate whether the absence of enactment recall effects in Experiment 1 was due to the splitting of the information at recall that followed from asking participants to selectively retrieve either the actions or the objects presented. Thus Experiment 2 examined memory for whole action-object phrases under enactment or verbal recall after verbal encoding. Based on the literature, it was hypothesised that enactment recall would lead to superior memory performance compared to verbal recall when whole action-object phrases are examined. We examined this prediction partly by examining participants' ability to recall both the action and object within a presented pairing. However, given our interests in the potentially separable effects of enactment on action and object recall, we also recorded and analysed participants' recall of either just the action or just the object of any partially remembered pairing.

Method

Participants

A total of 41 university students ($Mean_{age}$ = 20.83, SD_{months} = 1.23) took part in the study in exchange of course credits (though see below for final sample details). None of the participants in this experiment had taken part in Experiment 1. The project was approved by the University of Nottingham Ethics committee.

Material

The material used were identical to Experiment 1, with the following modifications. A total of 10 action verbs (tap, roll, shake, drop, push, squeeze, turn, hold, scratch and rub) and 10 numbers (0-9) were used to create the instructions. All trials had a fixed length of 5 action-object pairs per trial and there was only 1 second delay between the presentation of each instruction pair. Two blocks of instructions were created, each containing 16 trials. Each action-object pair appeared once in each block. The order of block presentation and recall condition was counterbalanced across participants.

Design

The study employed a repeated measures design, manipulating recall type (enactment vs. verbal). The dependent variable was serial recall accuracy and it manifested in two levels; pair recall and feature recall. For pair serial recall, a response was scored as correct if both the action and the object part of the pair were recalled correctly in the correct position. In feature serial recall, accurate serial recall of actions and objects was calculated independently of whether the whole action-object pair was retrieved successfully (i.e. feature scores).

Procedure

Participants sat at a table facing the objects which remained visible throughout the experiment. Two experimenters sat at the right side of the table, recording participants' responses. Participants completed a total of 4 practice trials for each recall condition. During the encoding phase, participants listened passively to the action-object pairs. There was a one second delay between the presentation of each pair. At the end of the trial, a green star appeared on the screen, signifying recall. In the enactment recall condition, participants were asked to recall the action-object pairs in the correct order by enacting them. In the verbal recall condition, participants were asked to verbally recall the action-object pairs in the correct order.

Results

Exclusion: As mentioned in the procedure above, the objects should have remained present and visible in front of the participant throughout the experiment. This was done to ensure that any differences between enactment and verbal recall performance were not due to visuospatial encoding strategies in the enactment condition. However, due to a systematic error in the administration made by one of the researchers, 17 participants did not have the objects present in front of them in the verbal recall condition. Although this did not affect their ability to complete the task, it did reduce the comparability of the two recall conditions for these individuals. In order to provide the most stringent test of our predictions, data from those participants were excluded from the current analysis and the results from 24 participants are reported below. However, an analysis including all participants showed the same pattern of results and is reported in Appendix A.

Table 4 shows the average proportion correct recall in each condition for action-object pairs. Additionally, the table displays the feature scores, separately for actions and objects. The feature scores reflect the total proportion of actions and objects recalled correctly in the correct position independently of whether the whole pair was successfully retrieved or not. Thus, feature scores are not independent of pair scores.

Table 4

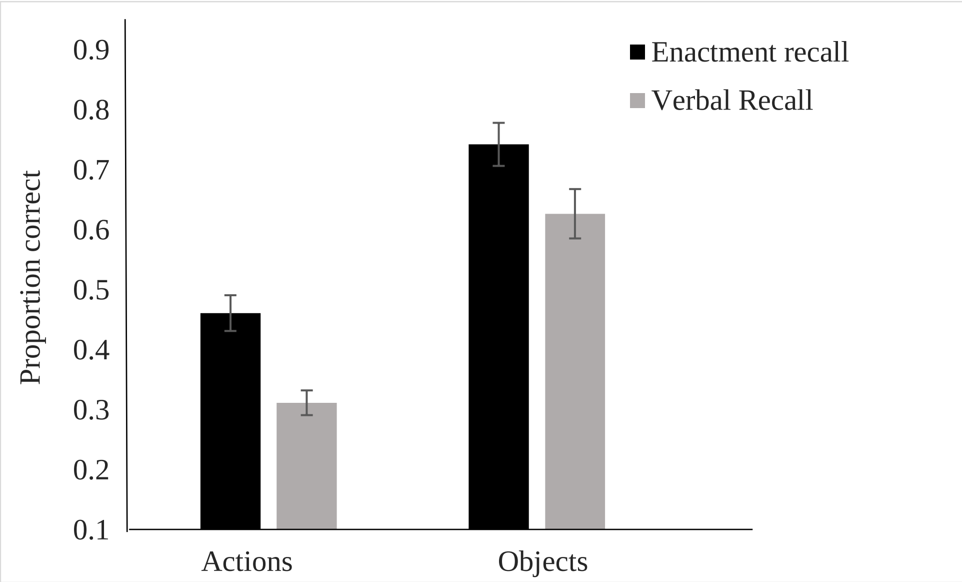
Mean proportion correct performance in enactment and verbal recall for action-object pairs as well as action feature scores and objects and object feature scores.

Recall	Pair Scores	Action-Feature Scores	Object-Feature Scores
	Mean (SD)	*Mean (SD)*	*Mean (SD)*
Enactment	.40 (.14)	.46 (.15)	.74 (.17)
Verbal	.24 (.10)	.31 (.10)	.62 (.20)

A paired samples t-test was carried out on pair scores to examine whether the difference between enactment and verbal recall of action-object pairs was statistically significant. The test showed that enactment led to significantly better memory of action-object pairs compared to verbal encoding, $t(23) = 8.138$, $p < .001$. Next, a 2x2 ANOVA was conducted on feature scores investigating feature type (action feature scores, object feature scores) and recall mode (enactment, verbal). Unsurprisingly given the previous analysis, there was a significant main effect of recall mode, $F(1, 23) = 54.689$, $p < .001$, $\eta^2 = .704$, as enactment led to superior memory performance compared to verbal recall. There was also a reliable main effect of feature type, $F(1, 23) = 114.541$, $p < .001$, $\eta^2 = .833$, reflecting the fact that object features were more frequently recalled than action features. The interaction between recall mode and feature type was not significant, $F(1, 23) = 1.101$, $p = .305$, $\eta^2 = .046$. This shows that although object features were recalled more frequently than action features overall, the benefit of enactment for action and object features was similar, see Figure 4. Note, however, that this analysis does not distinguish between cases when features were recalled within a bound pair with their corresponding action/object, or alone. Our next analysis therefore explored the effects of enactment recall on feature binding specifically.

Figure 4

Memory performance for actions and objects in enactment and verbal recall. Error bars represent the standard error of the mean.



Binding Analysis

In order to examine whether the binding of action-object pairs is facilitated by enactment recall, the conditional probabilities of recalling objects and actions either in a bound pair or alone were examined in a novel analysis. As discussed in the introduction, previous research (Yang et al., 2016), has examined binding using conditional probabilities in order to investigate the probabilities of features been recalled together. However, in the current analysis we were further interested to investigate not only how often features were recalled together, but also how often one feature was recalled in the absence of the other and if that differs according to the nature of that feature (i.e. action, object) based on recall type. Specifically, for both actions and objects the conditional probability of recalling that component of a pair in its bound form was calculated (i.e., the probability of recalling an action given the object in the pair was recalled), as was the conditional probability of recalling that component alone (i.e., the probability of recalling an action given the object in the pair was not recalled)[1]. These conditional probabilities are shown in Table 5.

Table 5

Mean (and SD) conditional probabilities of recalling either actions or objects in a bound pair or alone

Recall	Actions *M (SD)*		Objects *M (SD)*	
	Bound	Alone	Bound	Alone
Enactment	.54 (.13)	.29 (.17)	.86 (.11)	.66 (.22)
Verbal	.38 (.11)	.21 (.13)	.75 (.17)	.57 (.22)

A 2 (feature type: action, object) x 2 (recall mode: enactment, verbal) x 2 (probability type: bound, alone) repeated measures ANOVA was conducted in order to examine whether the bound and alone conditional probabilities differed across conditions for the different feature types. This analysis, revealed a significant main effect of feature type, $F(1, 23) = 145.426$, $p < .001$, $\eta_p^2 = .863$, reflecting the fact that object recall was greater than action recall overall and as already demonstrated in the preceding analysis (see Figure 4). The main effect of recall mode was also significant as enactment led to superior memory performance compared to verbal recall $F(1, 23) = 47.065$, $p < .001$, $\eta_p^2 = .672$ (again, see Figure 4). Of more interest is the fact that the main effect of probability type was significant $F(1, 23) = 55.084$, $p <.001$, $\eta_p^2 = .705$, with higher conditional probabilities for bound than alone recall. The interaction between feature and probability type was not significant, $F(1, 23) = 3.357$, $p = .080$, $\eta_p^2 = .127$, the interaction between recall mode and probability type was not significant $F(1, 23) = 1.330$, $p = .261$, $\eta_p^2 = .055$, nor was the interaction between feature type and recall mode, $F(1, 23) = .267$, $p = .610$, $\eta_p^2 = .011$. However, the three-way interaction between feature type, recall mode and probability type was significant $F(1, 23) = 10.920$, $p = .003$, $\eta_p^2 = .322$ (see Figure 5 panels a and b).

Figure 5a

Probabilities of recall for bound and alone actions under enactment and verbal recall. Error bars represent the standard error of the mean.

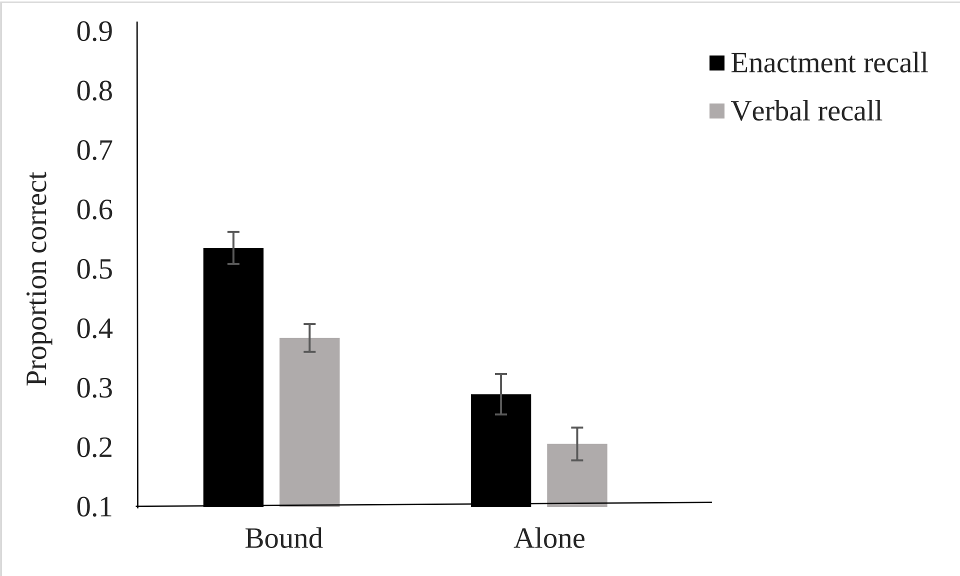
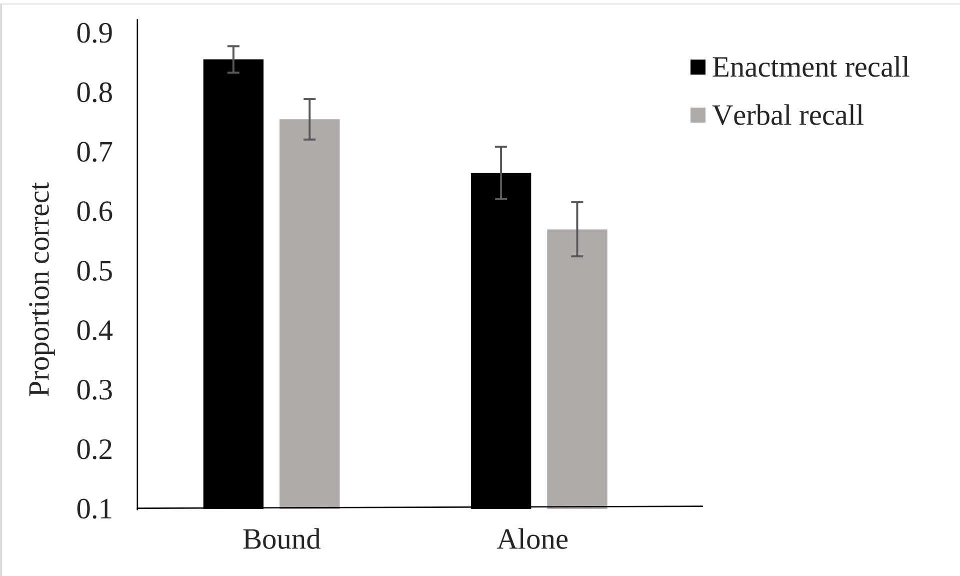


Figure 5b

Probabilities of recall for bound and alone objects under enactment and verbal recall. Error bars represent the standard error of the mean.



Further analysis sought to understand the source of this three-way interaction by considering the two conditional probabilities for each feature type separately. For action feature recall, a 2 (recall mode) x 2 (probability type) repeated measures Anova showed significant main effects of recall mode, $F(1, 23) = 21.973$, $p < .001$, $\eta_p^2 = .489$, and of probability type, $F(1, 23) = 60.749$, p <001, $\eta_p^2 = .725$, in line with the main analysis. The interaction between recall mode and probability type was close to significant, $F(1, 23) = 3.981$, $p = .058$, $\eta_p^2 = .148$. To investigate this further, a Bayesian analysis for this interaction was conducted using JASP, showing anecdotal evidence for the alternative hypothesis BF10 = 2.6. Further pairwise comparisons, showed that the probability of actions being recalled in a bound pair under enactment recall was significantly higher than the probability of actions being recalled in a bound pair under verbal recall, $t(23) = 6.558$, $p < .001$, d = 1.34. The probabilities of actions being recalled alone under enactment recall was also higher than in verbal recall, but with a considerably smaller effect size. $t(23)= 2.321$, $p = .030$, d = 0.47. Thus, the source of the potential interaction seems to be that enactment facilitated performance for bound features to a greater extent than alone features. The corresponding analysis for object recall showed the same significant main effects of recall mode, $F(1, 23) = 15.641$, $p < .001$, $\eta_p^2 = .405$, and of probability type, $F(1, 23) = 44.102$, p < 001, $\eta_p^2 = .657$, while the interaction between recall mode and probability type was not significant $F(1, 23) = 0.034$, $p = .854$, $\eta_p^2 = .001$.

Discussion

The aim of Experiment 2 was to investigate whether the absence of enactment effects at recall in Experiment 1 were due to the splitting of action-object phrases during retrieval in that first experiment. To examine this, Experiment 2 tested memory performance for whole action-object phrases while varying the presence of enactment at recall. It was hypothesised that enactment at recall would lead to better memory performance compared to verbal recall when whole action-object phrases are examined. In turn, this would strongly suggest that the absence of enactment at recall benefits in Experiment 1 were indeed due to the splitting of action-object phrases.

In line with the predictions, as well as previous literature, (Allen & Waterman, 2015; Koriat et al., 1990; Yang et al. 2014, 2016), memory for whole action-object phrases was superior under enactment compared to verbal recall. Further, an initial examination of feature scores for actions and objects showed that although objects were better recalled than actions overall, they both benefited from enactment to a comparable extent, at least in terms of how often they were recalled either within the whole action-object phrase or alone. Contrary to Experiment 1 in which memory for objects did not benefit from enactment recall, Experiment 2 therefore showed that both action and object feature memory benefited from enactment when participants were instructed to recall both actions and objects as a bound pair at recall.

However, the novel binding analysis, which was able to distinguish between recall of features within a bound pair or in isolation, suggested that while memory of both object and action features was improved by enactment recall, these two feature types were affected by enactment in different ways. Enactment recall led to a comparable increase in object features that were recalled in a bound action-object pair and in object features recalled alone (see Figure 5b). This shows that enactment increased overall performance for objects and did not have a particular effect on the probabilities of objects being recalled as a bound pair compared to alone. In contrast, there was some evidence that enactment recall led to a greater memory increase for action features that were bound within an action-object pair compared to action features in isolation (see Figure 5a). This suggests that motor planning for future implementation increases action-to-object bindings, leading to more accurate pair recall performance compared to verbal recall. In other words, there is suggestive evidence that when planning for future physical implementation, participants bind the action to be performed on the specific object of performance, leading to more accurate action-object pair recall when the action feature is remembered.

These findings are consistent with Yang et al. (2016) who found that compared to verbal recall, enactment recall facilitated the binding of action-object phrases as examined using *feature binding* scores. These scores reflected the proportion of features (objects and objects' colours) recalled accurately with the correct movement. They showed that when the correct action was retrieved it was highly likely to be followed by the correct object. This is in line with the current findings which showed an increased binding effect for actions under enactment compared to verbal recall.

General Discussion

The aims of the two experiments reported here were to investigate whether any enactment advantage to immediate serial recall of a sequence of previously presented action-object pairings is mainly driven by a superiority for the performed actions, and to determine whether this effect is evident at both enactment encoding and enacted recall. Experiment 1 examined the effects of enactment separately for actions and objects in order to investigate whether the enactment advantage is rooted in better memory performance for performed actions. The findings showed that enactment specifically facilitated memory for actions when it was employed at the encoding phase. However, no benefits of enacted recall were observed for actions or objects. Given that enacted recall benefits are well-documented in the immediate recall literature (e.g. Allen & Waterman., 2015; Yang et al., 2014), it was assumed that the absence of such enactment effects in Experiment 1 were due to the novel manipulation of splitting action-object phrases at recall. In order to test this hypothesis, Experiment 2 used the same material and procedure but examined the effects of enacted recall when instructing participants to remember whole action-object phrases. The results showed a clear enactment benefit over verbal recall for action-object phrases. The same was true for action and object features when considered across cases when the whole action-object pair was successfully remembered or when only one feature was correctly recalled. However, a further examination of action-object bindings provided suggestive evidence that the enactment recall manipulation may selectively increase the likelihood of action features being remembered in a bound pair rather than alone; object features also benefitted from the enactment recall manipulation, but the size of this benefit was comparable for recall of object features within a bound pair and recall of object features in isolation.

Based on the findings of Experiment 2, it can therefore be argued that un-binding action-object phrases at retrieval, as in Experiment 1, reduces the advantage provided by enactment at recall but not the benefits of enactment at encoding (since an enactment encoding benefit for actions was observed in Experiment 1). This, in turn, provides evidence that enactment at encoding and enactment at recall involve, at least to some extent, different processes. More specifically, the current findings suggest that although action-object bindings are important for both successful enactment encoding and enactment recall, this relationship may be qualitatively different for the two phases. In the case of enactment encoding, this action-to-object binding may occur naturally when the participant physically performs the action on the specified object. In the case of enactment recall, the motor plans formed at presentation may integrate action and object information into action plans for future performance. This is in agreement with, Kormi-Nouri et al. (1994), proposal that enactment at recall benefits rely on *cue effectiveness* where the objects (when available in the environment) serve as a cue for correct recall of the action-object phrase, which implies that the binding process (action to object) plays an important role in enactment recall.

The pattern of findings therefore suggests that motor planning, including action-object bindings, plays a crucial role in facilitating enactment performance. Kormi-Nouri and Nilsson (2001) stressed the importance of action-object bindings in enactment, suggesting that the action is defined by the object that is acted upon, in a manner that leads to a unified representation. For example, according to this view, the instructions “lifting the pen” and “lifting the book” result in different motor movements. Thus, physical performance of the motor movement, binds the action and the object into one action unit or *action event* (i.e. *lifting a pen* as one action).

In turn, if physical performance, or the intent of it, serves as a “binding agent” which integrates action and object information into one unit, then it might partly explain any benefits of enactment. For example, consider the instructions used in the current experiment “drop the 6, tap the 4, shake the 1”. In this set of instructions, in a verbal encoding with verbal recall condition, the participant would have to remember 6 separate items in the correct order (i.e. verb and object x 3). However, in an enactment condition (encoding or recall), assuming we accept Kormi-Nouri and Nilsson’s (2001) hypothesis, this would be remembering only 3 items (as action and object have the tendency to be bound together and registered as one item, i.*e. dropping the 6*). In turn, this would decrease the memory load, leading to more accurate performance. This was demonstrated here by the novel analysis of conditional recall probabilities for action and object features recalled either within a bound pair or in isolation in Experiment 2. This suggested that actions were recalled in a bound pair more often than they were recalled alone to a greater extent under enactment compared to verbal recall. Thus, although bound recall was greater compared to recall of features in isolation under both verbal and enactment recall, action features were more likely to be bound than recalled alone in enactment recall.

A candidate framework that could potentially account for these processes is Baddeley and colleagues' most recent version of his working memory model that incorporates the episodic buffer (Baddeley et al., 2010). The episodic buffer is assumed to integrate representations from different modalities; in other words, it is responsible for binding multimodal information. Thus, rather than suggesting that a motor store supports enactment within WM, one might instead suggest that the episodic buffer plays a crucial role in enactment performance by means of integrating various representations into a unified representation that in turn, facilitates performance. The binding process itself, as examined in binding of multiple object features (i.e. object colour and object shape), is not thought to involve additional attentional resources (Allen et al., 2009) and may be automatic in nature (Baddeley et al., 2010). This automatic binding has been found to be the case even when object features are spatially separated or when there is a time interval between the presentation of the individual features of an object (Karlsen et al., 2010). One possibility is that the binding of action-object features behaves in a similar manner to object-feature bindings, thus not requiring additional WM resources. Future research should further examine the role of action-object bindings in facilitating enactment performance compared to standard verbal conditions. For instance, a future study could compare memory for action-object phrases to memory for single actions and single objects under enactment and verbal encoding and recall. If enactment facilitates recall of bound actions, then it would be expected that recall performance for action-object pairs would be superior to that seen for the equivalent number of single actions and single objects in enactment compared to verbal conditions. Further we would expect to find stronger evidence in support of the present binding analysis, showing that, compared to verbal recall, enactment selectively increases recall of bound action features compared to action features recalled alone, while we would not expect to see that distinction for object features.

To summarise, the previous literature has established that enactment leads to better immediate memory performance compared to verbal conditions both at encoding and recall. The current findings show that splitting action-object phrases at retrieval in an immediate memory task eliminates the advantage of enacted recall. This finding has two implications. First, it provides evidence that enactment at encoding and enactment at recall involve different processes. This is because motor planning for future execution was disrupted by the splitting of action-object phrases while memory for the already performed actions remained intact. Second, these findings indicate that enactment superiority for immediate recall is driven by action features, suggesting that the intention of enactment binds the action to the specific object of performance through the formation of object-specific motor plans, leading to higher pair recall rates. In the case of enactment encoding, the same action binding process may occur but through actual motor performance as discussed above. However, it should be pointed out that in order to make direct comparisons regarding action-object bindings between enactment encoding and enactment recall a further study is needed which employs the methodology of Experiment 2 but manipulates enactment at the encoding phase.

Overall, the current findings emphasize the importance of action-object bindings, underpinned by motor planning, in the manifestation of the enactment effect within immediate recall, offering a new avenue of exploration for future studies of the underlying mechanisms of the enactment advantage.

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Footnotes

[1] For example, participant 1 recalled a total of 22 actions, 66 objects and 18 pairs (action + object) correctly in the correct position out of the total 80 pairs presented. To calculate the object binding score the total pair score (18) was divided by the total number of actions recalled correctly (22) (i.e. 18/22 = .82). The alone score was calculated by dividing the number of trials the objects (but not the actions) were retrieved correctly (i.e., 66-18 = 48) by the total number of trials in which the action was not retrieved correctly (i.e., 80-22 = 58) (i.e. 48/58 = .83).

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Appendix

Results with 41 Participants- Experiment 2

The table below shows the analysis including all 41 participants prior to 17 participants being excluded from the main analysis due to a methodological error.

Table 1. Mean proportion correct performance in enactment and verbal recall for action-object pairs as well as action feature scores and object feature scores. The table also shows inferential statistics (paired samples t-test). Enactment recall led to superior memory performance compared to verbal recall for action-object pairs as well as actions and objects.

	Recall			
	Enactment *M (SD)*	Verbal *M (SD)*	*t*	*p*
Pairs	.37 (.14)	.23 (.11)	8.51	< .001
Actions	.43 (.14)	.30 (.11)	7.89	< .001
Objects	.73 (.16)	.59 (.20)	6.07	< .001